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Title: Measurements of the 8B and 7Be Electron Neutrino Fluxes from the Sun with a Cerenkov Triggered Radiochemical Neutrino Detector

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Measurements of the ^8B and ^7Be ν_e Fluxes from the Sun with a Cerenkov Triggered Radiochemical Neutrino Detector

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The rate of flavor transformation of solar ν_e into other neutrino species can be measured by using the difference in interaction rates in detectors that rely on neutrino-electron scattering and those that utilize the inverse beta decay interactions of ν_e. We plan to measure the latter rates for both ^8B and ^7Be ν_e from the Sun by use of an electronically triggered radiochemical detector. In this detector, a set of photomultiplier tubes detects the Cerenkov radiation generated by neutrino interaction secondaries and initiates a fast extraction of the secondary atom from the detector and directs this atom to a specific charcoal storage trap.

The first measurement of the solar neutrino emission, in 1968 by Raymond Davis[1], indicated that the observed electron neutrino flux was about 1/3 of that predicted. Pontecorvo immediately suggested that ν_e from the Sun might convert to $\bar{\nu}_e$ or ν_μ in the transit from the Sun to the Earth in a manner similar to the vacuum $K^o \rightarrow \bar{K}^o$ transition observed a decade earlier suggested [2]. This suggestion opened the possibility of a time dependent change in neutrino flavor. The idea was expanded in 1986 by Mikheev and Smirnov[3] who extended the Pontecorvo neutrino flavor transition idea to involve transitions that might involve a matter transition (MSW) inside the Sun. Such transitions require mass differences between the two flavors of neutrinos involved and so introduce a neutrino mass scale. The combination of mass difference and coupling strength can be used to generate an energy dependence of the neutrino flavor mixing probability that can generate an energy dependent reduction of the observed neutrino solar neutrino flux.

Additional evidence of unusual neutrino behavior has been observed with neutrinos produced in the upper atmosphere by cosmic rays. These observations indicate that there is a deficiency of muonic neutrinos coming upward that have traveled through most of the Earth's diameter compared to those coming downward which have a relatively short flight path from production to detection[4]. Electron neutrinos do not show such an effect; their flux appears independent of flight path over the available range. The interpretation of these observations is that ν_μ convert into another neutrino flavor, but not into ν_e and so either sterile neutrinos or ν_τ.

In summary, we have two different disappearance observations that suggest neutrino flavor transitions, $\nu_\mu \rightarrow \nu_\tau$ for atmospheric neutrinos and $\nu_e \rightarrow \nu_\mu$ for solar neutrinos. Unfortunately, all the present observations involve the disappearance of neutrinos. There still is no observation of the **appearance** of the transformed flavor neutrino. **Appearance** of the transformed flavor neutrinos is critical to the demonstration that neutrino flavor transitions occur and so is the goal of the next generation of neutrino observations.

Since the energy range of atmospheric neutrinos extends into the multi-GeV range, some fraction of these neutrinos are energetic enough to produce τ mesons. Indeed, if the neutrino flavor transition hypothesis is correct, then the Superkamiokande detector already has about 100 τ produced within it. The question is, can these be reconstructed and recognized?

Unfortunately, the solar neutrino spectrum only extends to 14 MeV so that there is no possibility of observing neutrino interactions that can make charged muons. The only recourse is to utilize the difference in measured solar neutrino flux between a detection mode that is sensitive to all neutrino flavors and one that is sensitive to only ν_e. This must be done separately for ^8B neutrinos and for ^7Be neutrinos.

The neutrino-electron elastic scattering reactions observed by Superkamiokande are the sum of charged current ν_e - e scattering and neutral current ν_{all} - electron scattering. By subtracting the charged current ν_e flux from the total Superkamiokande measurement, we will have the flux of non-electron neutrinos from ^8B in the Sun. The ^8B electron neutrino flux can be obtained from inverse beta decay reactions on

nuclei such as $^{37}Cl(\nu_e,e^-)^{37}Ar$ as observed by the Homestake chlorine detector, or $^{2}H(\nu_e,e^-)pp$, as observed by the charged current reactions at SNO.

If the Superkamiokande neutrino-electron scattering events are interpreted as all due to electron neutrinos from ^{8}B, then that flux is $2.44 \pm 0.09 \times 10^{6}$ ν_e/cm^2 sec^5. To compare this result with that from the chlorine detector we must multiply by the cross section for ^{8}B electron neutrinos in ^{37}Cl, $1.14 \pm 0.04 \times 10^{-42}$ cm^2.[6] This gives a chlorine equivalent rate assuming that the SK measured flux is all electron neutrinos of 2.78 ± 0.13 SNU. This result is quite consistent with the direct chlorine detector measurement of the solar electron neutrino flux of 2.56 ± 0.23 SNU[7].

The conventional interpretation of this result is that the above two measurements are of the same signal, namely all electron neutrinos from ^{8}B. This implies that the chlorine detector does not see any electron neutrinos from ^{7}Be. Of course, ^{7}Be must exist in the Sun since ^{8}B is formed by $P + {}^{7}Be \rightarrow {}^{8}B + \gamma$. Since only about 1/1000 ^{7}Be is involved in ^{8}B production, the ^{7}Be decay rate should be about 10^3 times the ^{8}B formation and decay rate. This solution, therefore, strongly suggests that essentially all ^{7}Be electron neutrinos convert to muon neutrinos on their way from the solar core to the Earth.

There is, however, another possible interpretation of the SK and chlorine data, that each of these signals contains another component. For SK, that component is non-electron neutrinos from ^{8}B while for chlorine, that component is low energy electron neutrinos such as those from ^{7}Be. Since there is no way to distinguish ν_μ interactions from ν_e interaction in the SK detector, it is necessary to add to the information obtained for the chlorine signal, the energy distribution of the electron neutrinos that interact.

2. The Hybrid Detector - a photomultiplier triggered radiochemical detector

We have proposed doing the above by converting the chlorine detector from a purely radiochemical detector to a hybrid electronic-radiochemical detector. This would be achieved by adding a set of photomultiplier tubes to the detector. These tubes would be used to detect the Cerenkov signal produced by the secondary electron from the $^{37}Cl(\nu_e,e^-)^{37}Ar$ reaction. Whenever such a signal is observed, the detector would be swept with a pulse of helium and the recovered ^{37}Ar atom would be stored in a specific charcoal trap dedicated to ^{8}B events.

There are several technical details that must be dealt with in designing such a detector. First, the extraction time must be short compared to the rate at which ^{37}Ar atoms are produced. Second, the rate of false triggers, events in which there is a Cerenkov pulse but no production of ^{37}Ar atoms, must also be low compared to the extraction time to avoid excessive detector dead time. Third, we must be able to distinguish between the various channels for ^{37}Ar production, cosmic ray muons, ^{8}B neutrinos, ^{7}Be neutrinos and neutrons of local origin.

The first two conditions can be achieved by dividing the detector into a number of separate modules, each with a separate set of triggering photomultiplier tubes and a separate extraction system. Any given pm signal initiates an extraction in only one module. The remaining modules remain active. In addition, smaller modules also permit shorter extraction time constants, enhancing the effect.

3. Background rates

A cosmic ray induced ^{37}Ar production will generally consist of a very high energy through going muon, ~2 TeV, producing one or more nucleons in or near a given module followed by one of the secondary protons undergoing a $^{37}Cl(p,n)^{37}Ar$ reaction. The neutron that emerges from this reaction will moderate in the module and finally capture on a ^{35}Cl producing a ^{36}Cl and about 7 MeV of gammas. The initial muon will result in a very large pulse. The delayed neutron capture gammas will then generate a second pulse within a millisecond of the first pulse. This signature is quite distinctive.

Our estimates for cosmic ray induced ^{37}Ar production rate at the depth of the present chlorine detector, 4200 mwe, is about 1/10 of the production rate due to neutrinos. We anticipate that at least 90% of cosmic ray muon induced ^{37}Ar production will result in such a two pulse signal. This leaves us with a potential cosmic

ray contribution to the one pulse events that is less than 1% of the neutrino induced ^{37}Ar rate.

The local neutron induced rate is somewhat more difficult to estimate. The mechanism consists of a (n,p) process to produce a fast proton, followed by the same $^{37}Cl(p,n)^{37}Ar$ and delayed neutron capture as with the cosmic rays. Since there are no free protons in C_2Cl_4, the (n,p) reactions involve one of: $^{12}C(n,p)^{12}B$, $^{35}Cl(n,p)^{35}S$ or $^{37}Cl(n,p)^{37}S$. Since ^{12}B has a 20 ms half life and then decays by beta emission, we see a two pulse delayed pattern, only with a longer delay time. The first pulse will be due to neutron capture on ^{35}Cl with the second pulse arising from the ^{12}B decay. However, the high threshold, 13.4 MeV, makes this a very unlikely channel for this background reaction.

Unfortunately, ^{35}S has a 87 day half life and and beta decays with a very low energy end point so we will not see that second pulse. The low threshold for this reaction, 170 keV, suggests that this reaction could be the dominant channel for neutron induced background in C_2Cl_4. There is a chance that some fraction of the ^{35}S will go to an excited state and produce some deexcitation gammas that will provide a prompt, but small first pulse. Although these events will have the same time structure as the cosmic ray events, the first pulses will be very different for these two cases. The threshold for the production of ^{37}S is higher, 4.85 MeV. Combining this threshold with the requirement that the outgoing proton have at more than 2 MeV limits this channel to neutrons above 7 MeV, a very small fraction of the neutrons that are generated by radioactivity in the local rock.

The ^{7}Be neutrino produced ^{37}Ar will involve a 48 keV secondary electron and so will not produce any Cerenkov radiation. Since there is no Cerenkov signal for this interaction, we will periodically sweep each module, possibly every 3 hours or so, and store any extracted ^{37}Ar atoms in a "^{7}Be" labeled trap.

A similar analysis of neutron induced backgrounds in NaI dissolved in water leads to a much better recognition scenario. There are four target atoms of interest, ^{1}H, ^{16}O, ^{23}Na and ^{127}I. The n,p elastic scattering reaction always results in a secondary neutron. A second such neutron is emitted from the (p,n) reaction with ^{127}I. Thus, we are guaranteed to have two neutrons and thus two neutron capture pulses that provide a clear signature of background from this reaction. This is the dominant and only significant neutron induced background reaction in the NaI solution.

$^{16}O(n,p)^{16}N$ has a high threshold, 10.4 MeV, so this is an unlikely reaction for neutrons from the local rock. In addition, ^{16}N has a reasonably short life time, 7 seconds, so that a second pulse should be quite recognizable. $^{23}Na(n,p)^{23}Ne$ has a 4.4 MeV threshold. The combination of the Coulomb barrier of ^{127}I, about 10 MeV and this reaction threshold sets the effective neutron energy threshold at 14- 15 MeV. In addition, the life time of ^{23}Ne, 37.6 seconds, makes this a good candidate for two pulse recognition. The threshold for $^{127}I(n,p)^{127}Te$ is very low, 700 keV, so that this channel has significant possibilities for background production. However, the ratio of ^{1}H to ^{127}I in our solution is 16/1, so that the proton producing reactions with ^{127}I are a very small fraction of the background reactions in the iodine detector.

In summary, the high Coulomb barrier greatly suppresses neutron induced background in NaI and those that do occur have a very high probability of having a clearly recognizable two pulse pattern that can be used to label these events. Since unlabeled neutron induced events might be included in the ^{7}Be induced sample, from this point of view, NaI is a much more desirable target material than is C_2Cl_4.

4. "False" triggers

The most difficult and annoying problem will be "false" triggers, namely those that are initiated by relativistic electrons that results from Compton scattering, pair production, beta decay of radioactive contaminants or gammas from nuclear deexcitation that follows neutron capture. These occurrences do not result in ^{37}Ar production, but do produce a Cerenkov pulse that may be difficult to distinguish from ^{8}B neutrino induced events.

Fortunately, the ^{8}B neutrino interactions all exhibit large energies in the detector permitting a high solar neutrino event threshold. The neutrino cross section on ^{37}Cl as a function of energy, as given by Bahcall, et. al., ref. 6, multiplied by the ^{8}B neutrino spectrum gives an event spectrum that is strongly peaked at 10.5 MeV with only 10% of the events below 8 MeV.

We obtain an estimate of the nuclear dexcitation signal following thermal neutron capture from the measurement of this signal in the Gd loaded scintillator of the Palo Verde Neutrino Oscillation Detector.[8] This gives a scintillation spectrum that peaks at 6 MeV and ends at about 8 MeV. Thus, a cut at about 7 – 8 MeV would effectively separate the ^{8}B solar neutrino interactions from the neutron induced false triggers.

We have used the SK total signal rate as a function of energy to get an estimate of the false trigger rate. For 25 ton modules, we extrapolated a false trigger rate of one every three hours for a 6 MeV Cerenkov threshold and a lower trigger rate for a threshold at 7 – 8 MeV. Our detector will have a lower radon content than SK since the three hour ^{7}Be periodic sweep will also remove radon. Our shielding against external radiation will be poorer than that of SK.

The above arguments suggest that most false triggers can be energetically separated from neutrino interactions. However, since it is difficult to generate reliable estimates of false trigger rates, we will set up a test module in the mine and measure this rate directly.

5. Extraction system

The argon atom extraction technique employed in the Homestake chlorine detector is to use a flow of small bubbles of helium to remove the argon atoms from the detector liquid. In that detector the bubbles were produced by use of a series of eductors, jet nozzles that employ a Bernoulli tube to pull helium gas into a stream of circulating detector liquid. The driving mechanism is a liquid circulation pump. This system works extremely well for a single large tank. Although it could also be used by a multi-module system, it would require a liquid pump per module, a fairly expensive and complex system.

We have opted for a different bubble generating system, one that has been developed in recent years for the oxygenation of waste water systems. It consists of a series of flexible membranes, each of which has a large number of bubble generating openings. Pressurized helium gas is delivered to the back side of each membrane. The gas pressure forces open each of the holes emitting a stream of bubbles.

We have chosen to use 1 mm diameter bubbles and set a bubble density of 10 per cm^2. Thus, for a vertical cylinder module with a 1.5 meter diameter, there will be over 10^5 bubble emitting holes in the membrane surface on the bottom of that module. A 1 mm bubble has a rise velocity of about 20 cm/sec or takes about 40 seconds to rise to the top of an 8 m high module. Our preliminary measurements indicate that the 1/e extraction time of this system at a given horizontal slice of such a module is 15 seconds or a 99% extraction efficiency in that slice in one minute. Combining the extraction efficiency in a horizontal slice with the bubble rise time suggests a 2 minute total extraction time in such a module. These measurements are in good agreement with the results of extraction modeling by M. Foygel[9]. It is important to stress that our tests were done on a 2 meter high module and that we have not yet tested an 8 meter high module.

Each module is connected to two gas manifolds, one that brings the helium gas to the module system and a second that carries the helium gas from the modules to the charcoal traps. Two electrically contolled valves connect each module to these two gas manifolds.
A number of charcoal traps are also connected to the gas manifold system. Each of these charcoal traps is also connected these two gas manifolds via two electrically operated valves. The helium gas is driven through the system by a diaphragm pump that is located in the gas return system between the exit of the charcoal traps and the input to the detector modules.

A typical event sequence will begin with a neutrino interaction in a given module that results in a Cerenkov pulse detected by the photomultiplier tubes in that module. The pulse size and pulse pattern will classify the event and determine the charcoal trap that will be used. Four electrical valves are then opened by the control computer, two of these are on the gas input and output of the module in which the event occurred. The other two are on the input and output of the charcoal trap where events of this type are stored. The diaphragm pump driven helium flows through the system for a predetermined extraction time, about 2 minutes.

If an event occurs in a second module during the extraction period of the first module, the control computer stores this information and then begins the second module extraction cycle as soon as

the first one is completed. Thus, the system can tolerate a false trigger rate of one event every two minutes or 30/hour with a detector inefficiency of 1/N, where N is the number of modules in the system. For example, a 50 module system with a false trigger in each module every 1.6 hours, would be able to operate with a 98% detection efficiency.

6. System safety

All module intrusions, namely the input and output gas lines and the photomultiplier cables, will be from the top. A valve or piping failure could result in air entering the module, but will not result in any loss or spill of detector liquid. The helium pump will not be able to operate until all the appropriate valves are open and all other valves are closed. Since this is a completely closed loop system, the total amount of helium gas in the system is well defined. Each module will be pressure rated so that it can hold the entire detector gas volume without being overpressured. Each module will have an electrical pressure gauge so that overpressure can be immediately detected and stop the helium pumps. As additional pressure relief protection, each module exit valve will have a bypass pressure relief valve that connects to the return gas manifold and a second, higher set pressure valve that will connect to the outside atmosphere.

We do not anticipate a significant rate of valve failures. The only gas system components that are expected to require periodic maintenance are the pump diaphragms. We plan to use pumps will have double diaphragms so that the failure of one diaphragm will not allow outside air to enter the system. In addition, we plan to have a standby parallel pump in the system so that we can periodically interchange operating pumps and replace the diaphragms on the out of service pump. The indications from the manufacturer are that diaphragms should have multi-year life times in our mode of operation.

Since all valves will be normally (electrical power off) closed, a power failure will not have any effect on the gas and module isolation system. The heat capacity of the charcoal traps will keep them cold as long as the failure is fairly brief. A long duration power failure may result in a warmup of these traps. Since the input and output valves of each trap are closed, there should not be any loss of trapped signal atoms. Each trap will have a pressure relief valve which will open if the gas pressure in that trap becomes excessive. The process control computer will have a standby battery power supply so that it will remain operational during a power failure.

7. Photomultiplier trigger system

A set of photomultiplier tubes will be inserted into each module to detect the Cerenkov light pulses. Since our detector will not reconstruct the direction of the electron, there is no interest in the direction of the initial Cerenkov pulse nor in the precise time of light pulse arrival at each pm tube. We will add wavelength shifter to the detector liquid. This will provide isotropic emission of light and will increase the light in the blue region where the pm tubes are most sensitive by a factor of 3 - 4. We also plan to provide a highly reflective surface on the inside of each module so that the light that is not absorbed by a pm photocathode will be reflected and be available for a subsequent pm detection.

The combined result is a total enhancement of detectable light by a factor of 20 - 25 compared to SK and SNO type detectors. This will permit a significant light collection with a fairly small number of pm tubes in each module.

8. Supernova neutrino burst detection

Supernova are quite rare occurrences whose internal dynamics can be very effectively probed by investigating the flavor, energy and time structure of the emitted neutrinos. The extremely high core density is sufficient to permit MSW flavor transitions from $\nu_\tau \rightarrow \nu_e$. The high energy ν_e made in the collapsed core will find the local neutron sphere opaque. This will result in a fairly low energy at which ve can get through this obstacle. Neutrinos of other flavors will not be effected by the $\nu_\tau \rightarrow \nu_e$ flavor transitions that occur outside this neutron sphere will recreate high energy ν_e. The measurement of the detected ν_e flux and energy distribution will test for this occurrence and may permit a measurement of the ν_τ mass.

The supernova signal will consist of a number of interactions within a few seconds. Some fraction of these pulses will be greater than the upper

limit of the solar neutrino spectrum. The pattern is quite distinctive and will not be confused for a conventional cosmic ray interaction or solar neutrino signal. The rate of events within a few seconds will not permit extraction of individual atoms. Instead, a total detector sweep will be carried out after such an event with the argon atoms stored in a standby charcoal trap. We intend to participate in the International Supernova Watch and keep a UTC correlated clock readout on our control computer record.

9. Detector target, ^{37}Cl or ^{127}I?

Although the above discussion is based on the use of perchloroethylene, C_2Cl_4, as the detector fill, we actually have a choice of two different targets, ^{37}Cl in C_2Cl_4 and ^{127}I[10] in NaI dissolved in water. Both of these liquids are transparent to visible light, and have the same index of refraction, 1.5 and density, 1.6. Thus, they would be interchangeable in the proposed modules. There are, however, a number of differences in background sensitivities and in neutrino cross sections.

The dominant background sensitivity difference between ^{37}Cl and ^{127}I is due to the difference in nuclear charge, Z=17 and Z=53, respectively. This difference in nuclear charge is reflected in the effective Coulomb barrier of each of these nuclei. For Cl, the effective threshold for the protons in $^{37}Cl(p,n)^{37}Ar$ is about 3 MeV while the equivalent threshold for $^{127}I(p,n)^{127}Xe$ is about 10 MeV. This difference is quite significant since neutrons from radioactivity in the local mine rock are 8 MeV or less. These neutrons then must undergo a (n,p) reaction to produce the required proton.

As an example of this background effect, the rate of cosmic ray induced ^{127}Xe production in a NaI solution is about a factor 20 smaller than the corresponding rate of ^{37}Ar production in C_2Cl_4.

In addition to a lower background sensitivity, ^{127}I also has a larger neutrino cross section by a factor of 4 - 5 than ^{37}Cl.

There is, however, one distinctive advantage to ^{37}Cl, we presently have a better knowledge of the cross section. The cross section for ^{7}Be neutrinos is determined by time reversal from the lifetime of the final state, ^{37}Ar. The cross section for ^{8}B neutrinos is determined from relationships among the various constituents of the A=37 system. The presently stated cross section is $1.14 \pm 0.03 \times 10^{-42}$ cm^2. The cross section for the supernova energy region is given as 1.2×10^{-40} cm^2.

For ^{127}I, the cross sections are determined from (p,n) measurements. A neutrino cross section measurement was done in the 90° neutrino room at the beam stop at LAMPF. The precision of these measurements are in the 15 - 30% range.

There is in place a program to measure these cross sections for ^{127}I to high precision. The cross section for ^{7}Be will be done with an intense (1 -2 megacurie) source of ^{37}Ar. The emitted monoenergetic neutrinos from this source are at 814 keV, which lies just midway between the $^{127}I \rightarrow ^{127}Xe$ threshold of 789 keV and the energy of the ^{7}Be neutrinos 862 keV. The ^{37}Ar source is being prepared in a Russian fast neutron reactor, BN-600 by $^{40}Ca(n, ^{4}He)^{37}Ar$. The calibration is scheduled to be carried out in the fall of 2003.

The high energy neutrino, ^{8}B and supernova, calibration will be done with neutrinos from the beam target of the SNS. It is anticipated that this calibration will be carried out in 2006. The anticipated precision is 1 - 2%. We also hope to do a similar direct neutrino cross section calibration of ^{37}Cl at the same facility.

Given the relative merits of the two detectors, it may be sensible to utilize a mix of the two nuclei and fill half of the modules with C_2Cl_4 and the other half with NaI dissolved in water. That way we can get a good check on the effect of backgrounds as well as some redundancy on the ν_e fluxes from ^{7}Be and ^{8}B. Given the centrality of these measurements in the search for the **appearance** of ν_μ from the Sun, redundancy may be very important.

10. Detector mass

There is also the question of the appropriate detector mass. For a modular detector whose mass can be gradually increased, this question is not as important as it is for a single unit detector. The initial stages of our detector mass plan are based on a combination of understanding and verifying the detector operating characteristics and the background rates. Once the various preliminary tests have been successfully completed, we plan to construct and operate one full size module. This system already involves the gas manifold system, the control system, the

diaphragm pumping system and at least one charcoal trap. When we are satisfied with the single module, we will expand to a 15 - 20 module system. A 20 module C_2Cl_4 system with 25 tons of detector mass per module is reasonably close to the mass of the present chlorine detector and so provides a good basis for comparing rates between the standard radiochemical and the hybrid system. Operation of this system will also assure us that there are no complications in operating a multi-module system.

Once we are satisfied that the hybrid detector system is operating properly and that the data can be understood and is in agreement with that of the pure radiochemical system, we will embark on a gradual expansion of the detector to a 50 -100 module system or a total detector mass of several kilotons.

Another way to approach the question of final detector mass is to focus on the statistical precision that we wish to achieve in a given running period. For example, if we wish to get a 2 - 3% statistical result in three years of operation, 900 - 2500 counted events, we need between one and three counted events per day. With C_2Cl_4 we get 0.8 ^{37}Ar produced per day per kiloton detector mass. This should give about 0.5 counted ^{37}Ar per day per kiloton. A 100 module C_2Cl_4 system will have a mass of 2.5 kilotons and thus give 1.2 counted events per day or about 1300 in a three year period, a 3% statistical result. The same detector volume filled half with C_2Cl_4 and half with NaI dissolved in water will result in about 650 ^{37}Ar and 3000 ^{127}Xe. The statistical precision of such a measurement will be in the sub 2% range. Of course, we have only addressed one of the systematic errors, that associated with the cross section. It is quite conceivable that the rest of the systematic errors will be the limiting factors in the overall precision of this measurement.

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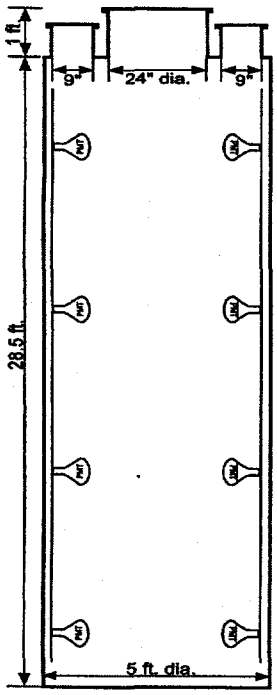

FIG. 1 The photomultiplier arrangement and access ports of a single detector module are shown. The photomultiplier tubes are housed in two plexiglas tubes that enter the module through flanges in the top of the module. These plexiglas tubes serve to isolate the photomultiplier tubes from the detector fluid and permit serving of the pm tubes without opening the detector volume. The plexiglas tubes will be filled with mineral oil. Since the detector liquid, the plexiglas and the mineral oil have the same index of refraction, there will not be any light reflections at those interfaces. The center flange of the module is used to install the gas diffuser elements and provides an exit path for the flushing gas. All detector monitors such as a pressure gauge also are attached to this flange. There are no holes or access points in the bottom of the module to avoid any possible sources of leaks.

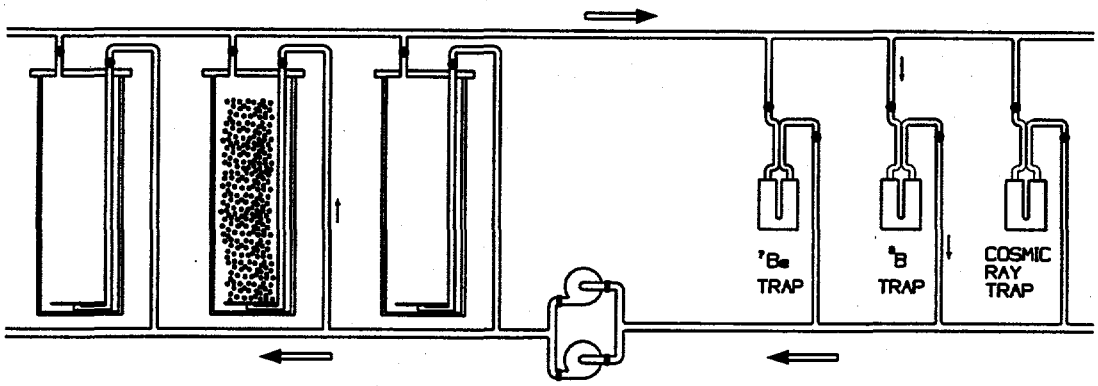

FIG. 2 This diagram shows the gas manifold system with three detector modules on the left and three charcoal traps on the right. In this example a Cerenkov trigger with a ^{8}B pulse pattern has just occurred in the middle detector module. The sweeping gas flows from the diaphragm pump on the bottom through the supply gas manifold to the module. Inside the module, the gas flows into the gas diffusers on the bottom of the module, bubbles through the detector liquid and then exits through the top. The gas then goes through the top gas manifold to the charcoal trap array. In this case the sweeping gas passes through the center charcoal trap, the one that collects ^{8}B neutrino interaction secondaries. The charcoal trap for supernova events was omitted to save space. Additional detector modules can be attached to the gas manifold ends on the left. Modules can be added with significantly disturbing the operating system.